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What is the future of the ecosystem services of the Alpine forest against a backdrop of climate change?

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EDITOR'S NOTE

Translation: Accent Mondial

1 The French mountain forest provides a large number of ecosystem services (Millennium Ecosystem Assessment, 2005). The mountain forest surface area is very large: about 40% of the surface area of the seven French départements Isère, Savoie, Haute-Savoie, Drôme, Hautes-Alpes, Alpes-de-Haute-Provence, Alpes-Maritimes, are covered by forest, compared with the national average of roughly 30%. The first service recognised is wood production: 7.5 million m^3/year for these seven departments (National Forest Inventory 1996-2002), comprising more than 60% of conifers. In mountain areas, the forest provides a special service in protecting against human activities, avalanches, rock falls and erosion (Gauquelin and Courbaud, 2006). It is predominant in mountain landscapes and contributes to the cultural identity of these territories and indirectly to other business sectors such as tourism. Mountain forests are relatively unfragmented and are managed less intensively than in the plain. This makes them an interesting reservoir of biodiversity. Carbon storage is also an important service, in relation to the significant surface areas and standing volumes. Lastly, the timber industry accounts for approximately 4.13 jobs for 1000 m^3/year of timber harvested.

2 Climate changes are going to transform the mountain forest, first directly through the effect of the climate on vegetation and indirectly through changes in the socio-economic context and the demand for forest services. This article discusses the risks of jeopardising

ecosystem services and the appropriateness of mitigation and adaptation strategies that will accompany these changes as best as possible.

A lot of uncertainty concerning the direct impacts of climate change on mountain forests

The decisive influence of the climate on vegetation

3 The climate is the main causal factor of the regional distribution of tree species in the temperate area (Morin *et al.*, 2007). Local climatic conditions also have a decisive influence on the composition and workings of the mountain forest. This is seen in the layering of vegetation with higher elevations. For example, alpine forests are dominated by hardwood at the colline zone (oaks, beech, maple, limewood, etc.), mixed hardwood and conifers at the mountain level (beech, fir, spruce, etc.), and then mainly with conifers at the subalpine level (fir, mountain pine, Swiss stone pine, larch, etc.). The first factor that explains this layering is the decrease in temperature as the altitude increases (0.6°C per 100 m on the average), even if variations in atmospheric pressure and sun radiation also play a role. Temperature has an impact on growth in particular by determining the length of the vegetation season and growth speed, the fertility of trees, germination of seeds and the mortality of seedlings (frost). The other major climatic variable is the rainfall regime, which affects in particular, differences in vegetation between the external Alps (high rainfall, up to 2000 mm per year in the Haute Savoie department) and internal Alps (low rainfall, often less than 1000 mm/year in the Hautes-Alpes and even 550 mm/year in the Valais region of Switzerland). Humidity and groundwater resources have a huge impact on the growth, regeneration and the survival of trees. For example, there are no beeches in the internal zones of the Alps because there is not enough rainfall whereas larches thrive there because of the low atmospheric humidity (Ozenda, 1985).

4 All general atmospheric circulation models predict that by the turn of the century, there will be major changes in temperature and rainfall, due to the increase in concentration of atmospheric CO_2 According to climatic scenarios, the models predict an increase in temperature from 2.2 to 5.1°C in the Alps (IPCC, 2007). There will be a 20%-30% drop in summer rainfall but a 0-10% increase in winter rainfall). Rainfall type should also change: the lower limit of snow should increase with higher elevations and the duration of snowpack should decrease (IPCC, 2007). Nevertheless, it must be noted that predictions concerning a change in rainfall regime are not considered as reliable by climatologists themselves (IPCC, 2007). Climatic models also predict an increase in the variability of climatic conditions (IPCC, 2007) and the frequency of extreme events: drought and storms, although this is more controversial (Beniston *et al.,* 2007). Such climate changes are bound to affect the composition, structure, and dynamics of the forest populations of the French Alps.

Significant direct impacts on ecosystems that are not easily quantified

5 First of all, the forecasted increase in temperature should result in the shift of the vegetation belts to higher elevations. For example, a 4°C increase would lead to a shift of approximately 700 m). Temperatures in the Alps have already increased by nearly 1°C

since 1950 (IPCC, 2007). A shift to higher elevations has already been demonstrated for most forest plant species in the French Alps (Lenoir *et al.*, 2008), for mistletoe in Switzerland (Dobbertin *et al.*, 2005), beech in Spain (Penuelas and Boada, 2003) and for seven species of trees in Scandinavia (in particular birch, spruce fir and the Scots pine) (Kullman, 2002). It must however be noted that in the Swiss Alps, the upward shift in the forest treeline seems mainly due to the abandonment of pastures (Gehrig-Fasel *et al.*, 2007). Niche models, which establish a statistical relationship between climatic variables and the presence-absence of species, all predict a shift to higher elevations of the potential area of forest species, resulting in a major reorganisation of communities (Badeau *et al.,* 2004; Bolliger *et al.,* 2000; Piedallu *et al.*, 2009; Thuiller *et al.*, 2005). Given the high variability of local climatic conditions related to relief, these changes should be particularly significant and should lead to a considerable loss of mountain biodiversity (Thuiller *et al.* 2005).

6 An increase in forest productivity is expected in addition to these changes in specific composition. A sharp increase in tree growth has already been observed in Europe (Spiecker *et al*., 1996), and studies conducted at low elevations in north-east France show a rise in productivity of beech (Bontemps *et al.*, 2010) and oak (Dhôte and Hervé, 2000), that could be as high as 50% compared with the 1930s and 1940s. These changes in growth are usually linked to the increase in atmospheric CO_2 concentration, although nitrogen deposits and temperature increases could also be a cause (Boisvenue and Running, 2006). The phenological stages of trees (in particular, the appearance of leaves) depend strongly on temperature, and the lengthening of the vegetation period by several days has been observed in recent decades (Root *et al*., 2003). This increased productivity should continue in the future, at least in the short and medium term {Lindner, 2010 #1701}.

7 The response of forest species is however complex. Changes in species distribution will depend on some limiting factors where there is still very little knowledge. Seedlings react more to climatic changes than adult trees, and therefore, their survival will be decisive for the upward shift (Svensson *et al.,* 2005). The impact of the new climatic conditions on the mortality of adult trees is also not well known, even if high mortality rates as a result of extreme drought events have been reported, for example in the Californian Sierra Nevada (Breshears *et al*., 2005). Future changes in specific composition and the different responses of species to the new abiotic conditions (temperature, rainfall, CO_2) will certainly change the competition relationship between species. The impact of forest pests may be decisive: increasing damage related to attacks by sub-cortical insects such as bark beetles has been observed in connection with an increase in multivoltinism (ability to produce several generations per year) (Lindner *et al.,* 2010). In general, the response of plants to extreme events (drought and heat waves) is not very well known.

Resilience of mountain forests

8 The diversity and heterogeneity of mountain forests are the main assets that favour their resilience to climate change. Mountain forests are characterised by extreme geomorphological, micro-climatic and soil-type diversity. Because they are difficult to access, these forests are generally under relatively extensive and not very artificial management. Natural regeneration (i.e. without resorting to planting) is prevalent in these forests, even if the mountain land restoration policy required planting over large areas at the beginning of the 20th century. This context leads to a diversity of tree species

that is in a way an insurance against an uncertain future because it increases the odds of at least some local species being able to tolerate future conditions. The very sharp environmental gradients along the slopes mean that the distances to cover before finding favourable climatic conditions are much more limited than in the plains (Jump *et al.*, 2009). Despite the segmentation linked to the relief, the relatively low fragmentation of the mountain forest (it covers more than 40% of the surface area of the French Alps) ensures connectivity between forest habitats. These two phenomena should have a positive impact on migration processes. The high genetic diversity characteristic of trees should also allow for a relatively fast genetic adaptation (Lindner et al. 2010). Lastly, farm abandonment, in particular the abandonment of pastures, facilitates the upward shift of the treeline in the subalpine belt, by reducing the pressure of herbivores on the seedlings that colonise this zone.

9 In the past, mountain forests have shown strong capacity for resilience after disturbances. Although they were often damaged by storms during the last century, they generally regenerated very quickly. The proximity of seed sources and the presence of many pioneer species boosted this trend. These different elements give the impression that mountain forests should demonstrate high resilience to disturbances stemming from climate change. However, we must point out that there may be synergies between natural disturbances and climate change with complex effects that have never been observed until now (for example, development of forest fires or combination of drought years and storm years and an increase in pests).

Changes in forest service demand and forest management adapted to climate change

Increased demand for all the services provided by the forest

10 Climate change should also have an indirect impact on the mountain forest as well as an indirect impact through the increasing demand for forest services. The total wood harvest in France is estimated at 60 million m^3/year (Puech, 2009). The increase in the cost of fossil energy, combined with the resolutions taken to reduce their use, should boost the demand for energy wood in the medium term. One of the objectives proposed during the 2007 Grenelle de l'Environnement roundtable was to increase the proportion of renewable energy in the total national energy consumption to 23% by 2020. This includes the contribution of biomass requiring the mobilisation of 12 million m^3/year of additional energy wood (Grenelle de l'environnement - Operational Committee N° 10, 2008; Madignier and Guitton, 2009). This forecast is based on a felling scenario that is closer to the observed increase (at the national level, only 60% of the forest increase is apparently being exploited at the moment), a general increase in forest surface areas and the development of areas dedicated to energy wood production such as very short rotation coppices. The mountain forest is concerned by these objectives because it currently has very large deposits of standing trees. However their exploitation is curbed by the difficulty in access and mechanisation, even if the increase in energy wood prices will change profitability thresholds. Furthermore, the mountain forest is dominated by resinous trees for which energy wood will probably remain a product associated with timber.

11 The same change factors will apply in the longer term to the demand for timber, the relative competitiveness of which can only increase with the increase in energy prices. The Grenelle de l'Environnement roundtable is aiming at a 15% to 20% penetration of wood in construction materials by 2020, requiring the mobilisation of an additional 9 million m^3/year of wood. The Rhône-Alpes region appears as one of the three regions with the highest timber availability for the period between 2006 and 2020. It is also by far, the region with the highest availability in resinous timber (Ginisty *et al.*, 2009).

12 Aside from replacing or saving on fossil energy, the forest has another lever for reducing the greenhouse effect: its ability to capture and store carbon. It is in this connection that it was taken into account in the first commitment period of the Kyoto protocol (United Nations, 1998). Article 3.3 of the protocol imposes on signatory states to measure changes in the forest carbon stock resulting from changes in their forest surface since the baseline year, 1990. The result of this calculation is used to determine the emission balance of countries whether positive or negative. Article 3.4 allows voluntary states such as France to convert a fixed proportion of the increase in forest stock resulting from voluntary management actions into carbon credits (3.2 million tonnes of CO_2 equivalent/year for France). The carbon stored in forests thus indirectly acquires a value that increases or gives a new dimension to the social value of forests. However, these international commitments do not have a significant impact on the behaviour of owners, who are not paid for the service that they provide to the community by storing carbon on their property.

13 The storage capacities of carbon by the forest are limited by natural mortality. The Intergovernmental Panel on Climate Change (IPCC) therefore considers that "In the long term, a sustainable forest management strategy aimed at maintaining or increasing forest carbon stocks, while producing an annual sustained yield of timber, fibre or energy from the forest, will generate the largest sustained mitigation benefit." (National Forest Inventory, 2010; IPCC, 2007). With respect to mountains, a transitory phase of relative reduction in stocks is probable, or even preferable, because very large-diameter wood (diameters higher than 65 cm) are currently largely represented. These trees can rapidly lose their economic value (foot rot, injury, difficulty in sawing very large trees) and are vulnerable to parasite attacks and wind blasts (Gauquelin and Courbaud, 2006). It may therefore be advisable to harvest them while they are still marketable when there is a likelihood of an increase in extreme climatic events.

14 Climate change comes with an increase in risks related to natural vagaries such as violent rains and torrential floods. We can therefore also plan for an increase in the social demand for the protection service provided by the forest. Lastly, climate change increases the risks of a loss in biodiversity in all ecosystems and should reinforce the demand for preservation of forest areas for their service as a biodiversity reservoir.

Awareness of the potential effects of climate change on the forest by forest stakeholders

15 Forest stakeholders show contradictory signs of awareness of the possible impacts of climate change on the forest. The theme of climate change has rapidly become a central focus of forest research. There are many events and vulgarisation publications that deal with climate change (Legay and Mortier, 2006; Legay *et al.*, 2007).

16 The French Forestry Bureau (ONF) has defined a national strategy for adapting forest management to climate change in a five-page document (Office National des Forêts, 2009) that sets out the main principles such as the active surveillance of forests to reinforce responsiveness to emerging risks, active participation in research programmes, management of species changes and intensification of forestry, as well as improved management of health crises. With respect to forestry management, it recommends the identification of species at risk by type of ecological condition and their gradual replacement with other species, the maintenance of a moderate standing stock to reduce the risk of loss, the stepping up of forestry in line with the observed growth increase, the mixing of species, attention to soil settlement which increases water stress and the control of cervid populations to prevent the extinction of adapted species.

17 These orientations must be specified at regional level in regional directives for state forest management (Directives Régionales d'Aménagement pour les forêts domaniales - DRA) and regional plans for the management of forests of communities that fall under the forest regime (Schémas Régionaux d'Aménagement pour les forêts des collectivités relevant du régime forestier - SRA). The Rhône-Alpes DRA/SRA (Office National des Forêts - Direction Territoriale Rhône-Alpes, 2006) for example, recommends a change of objective species in certain sectors. Spruce firs at elevations under 1000 m and firs in Mediterranean forests are considered to be threatened by climate change, aggravated by biotic interactions such as bark beetles for spruce and mistletoe for firs. In such situations, these species must be limited in favour of more heterogeneous stands, by promoting the dynamics of hardwood and the development of larch, Douglas fir or cedar, depending on the context. A survey conducted with 25 forest operators in the Vercors region however reveals relatively little concern about the local consequences of climate change on the forest and the absence of a short-term adaptation project in this massif that was relatively spared by the 2003 drought (Rodron *et al.*, 2010 (in prep)) The large number of stakes and constraints (biodiversity, climate change, economic development), the various operators and the extent of uncertainties make it particularly difficult to define an adaptation policy, which risks creating a wait-and-see attitude among field operators.

18 For forest managers, the improvement in forestry efficiency seems to be an element of quick response to risks of decline and the increase in wood needs. However, there is still not enough feedback on this strategy. The strategy involves the cutting down of rotation periods, a reduction of logging diameters and the reduction of standing trees, in order to mitigate the risks of operating losses (decline of old trees or trees at the climatic border), the reduction in the water consumption of trees (Breda *et al.*, 2006) all the while increasing the wood offering. However, cutting down too many large-diameter trees could jeopardise the sustainability of harvests, the protective role and biodiversity. The reduction in large-diameter trees, as well as the exploitation of logging residues and stumps in relation with the development of the energy wood sector could be detrimental to certain species that depend on deadwood for nourishment or reproduction (Landmann *et al.*, 2009). With respect to voluntary changes in species, attempts to plant reforestation species are still marginal. Because of the many failures of introductions in the past and the negative image for biodiversity, the interest of reforestation as an adaptation to climate change is subject to debate. Controlled and targeted introduction in highly vulnerable areas could however be a possible strategy in the short-term. The objective of increasing forest production seems to be strongly reflected despite the contradictions

raised by the recurrence of unsold lots in mountain areas when logging conditions are very difficult.

Adaptation to climate change and development of services provided by the mountain forest

Risks related to under-adaptation

19 Faced with the uncertainty about the effects of climate change on the dynamics of the various forest tree species and the limitations of the action of forest operators, it is possible that forest management adaptations be set up relatively slowly on the field, in particular in forests that are not very productive. In terms of production, such a situation could result in the under-valuation of the forest, which does not take full advantage of the increase in productivity and subalpine forest areas surfaces. Insufficient logging could also lead to the development of stands that are either very dense or ageing, made up, in both cases of trees that are less resistant to wind and decline, which increases natural hazards (risk of fire related to the presence of deadwood, diminished protective role of the forest). Forest management therefore has an essential role to play here in maintaining production and protection services. A wait-and-see attitude concerning changes in tree species could lead to changes in production if there is an increase in hardwood to the detriment of resinous species (decrease in timber and increase in energy wood). There could also be a loss in forest productivity if southern types of tree species, which are less productive, replace mountain species (decline of fir, spruce and Scots pine, growth of pubescent oaks) (Roman-Amat, 2007). With respect to the protective role of forests and biodiversity, an increase in hardwood could be considered as positive in some cases (improved resistance of hardwood to rock falls, hardwood more natural than the black spruce plantations that were established in the Southern Alps at the beginning of the 20th century to fight erosion on marls). Nevertheless, a decrease in resinous species in mountain forests could result in the loss of the characteristic landscapes and ecosystems with a huge impact on the related animal and plant diversity. It therefore appears essential that forest operators implement actions to favour mountain species, in particular work to limit competition from colonising species. Lastly, it is indispensable that non-commercial forest services such as carbon storage, the role of reservoir of biodiversity or protection be better recognised by public opinion. This will enable them to effectively orient forest management adaptation to climate change.

Risks related to over-adaptation

20 The opposite situation of over-adaptation to climate change would also be detrimental. Excessively applying intensification strategies could lead to stripping and large clearings that would expose trees that on their own are quite unstable to wind. It would also result in a change in the forest microclimate and, depending on the case, to the drying up of regeneration, an explosion of blueberries and herbaceous vegetation or the development of impenetrable regeneration thickets. Although harvest would be increased in the short term, the various functions (production, protection and conservation of biodiversity) would deteriorate in the medium term. A sudden intensification of this kind would probably lead to the over-exploitation of stands that are easy to access, and the building

of road networks or rights of way for cables in the slopes exposed to natural hazards or with a high landscape impact. As things now stand, caution must also be exercised with respect to the voluntary changes in tree species through plantation. These actions are costly and their benefits are not guaranteed because future climatic conditions and related disturbance regimes could turn out to be different from the conditions currently encountered at lower elevations. Moreover, provision must be made for new soil and climate combinations. Artificial changes in tree species over large areas would have a negative impact on biodiversity with uncertain results in terms of production. Choosing tree species that are not well adapted could result in the decline of plantations. In extreme cases, some landowners would lose their investments which would discourage them and make them totally abandon their project.

Adaptive management and factoring in of uncertainties

21 Given these pitfalls, the challenge is to succeed in setting up adaptations to climate change that are measured, progressive and adapted to the local context. Field operators have stressed the importance of the close observation of ongoing changes at their scale as the prerequisite for the practical adaptation of management (Rodron *et al.*, 2010 (in prep)). We can hope for the development of interactions between management and research, inspired from the concept of adaptive management (Cordonnier and Gosselin, 2009). This approach would make it possible to organise observations, first around a more intensive and better quantified monitoring of forest ecosystems, and then around the setting up of more controlled and more diversified management actions. The purpose is to structure questions, quantify observations, share knowledge, agree on management targets and rally forces around large-scale systems.

22 Lastly, thought must be given to the development of adaptation strategies that take into account the uncertainties related to climate change (Hallegate, 2009). In this context, we can cite the "no regrets" strategies that consist in making investments that improve capacities to cope with climate change but that are beneficial even when absent. This is the case for example of investments in forest servicing or the development of cable logging. "Reversible" strategies enable flexibility in relation to climate change. The development of mixed stands is a good example because the presence of secondary species allows for the reversal of management orientations if a dominant species turns out not well adapted in the long term. In the case of climate or market fluctuations, mixed stands distribute risks evenly on species with different environmental and commercial characteristics that can be valued alternatively. Decision horizon reduction strategies also increase flexibility. In this case, we can imagine a reduction in forest management times. "Non-technical" strategies such as financial insurance for risks must also be considered, in particular for private owners and local communities.

Conclusion

23 Climate change is stressing mountain forests but at the same time also increases the perception of the forest by society because of increased expectations on the services provided by forests. Forest operators are currently reflecting on how to set up strategies to adapt forest management to climate change, despite the high uncertainty about the future changes to forests.

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ABSTRACTS

Mountain forests produce a large number of ecosystem services that are going to be affected by climate change. We are expecting an increase in high altitude species that could result in the decrease in resinous and subalpine species. These changes in species could adversely affect biodiversity and timber production. However, we also observe an increase in productivity that favours the production of energy wood and, at least temporarily, timber, as well as carbon storage. Given the possible rise in extreme climatic events, changes in vegetation could be marked by periods of decline, which will be very detrimental to the economic system, protection against natural hazards and biodiversity. Climate change will also have an indirect effect on the forest by increasing the demand for renewable energy and carbon storage. There is a lot of uncertainty about vegetation change predictions and this makes it difficult to define forest management adaptation strategies. Effective crisis management, monitoring of natural transformations of the forest based on the interaction between research and management (adaptive management) and the explicit factoring in of the concept of uncertainty appear to be essential to the maintenance of the ecosystem services provided by the forest.

La forêt de montagne produit de nombreux services écosystémiques qui vont être affectés par les changements climatiques. On attend une remontée des essences en altitude qui pourrait conduire à une diminution des résineux et des espèces du subalpin. Ces changements d'essences pourraient avoir un impact négatif sur la biodiversité et sur la production de bois d'œuvre. On observe cependant également une augmentation de la productivité favorable à la production de bois énergie et au moins temporairement de bois d'œuvre, ainsi qu'au stockage de carbone. Face à une augmentation possible des évènements climatiques extrêmes, les changements de végétation pourront être marqués par des épisodes de dépérissements, très négatifs pour la filière économique, la protection contre les risques naturels et la biodiversité. Le changement climatique affectera la forêt également de manière indirecte en augmentant la demande en énergie renouvelable et en stockage de carbone. Les incertitudes sur les prédictions de changements de végétation sont élevées, ce qui rend délicate la définition de stratégies d'adaptation de la gestion forestière. Une gestion de crises efficace, un accompagnement des évolutions naturelles de la forêt basé sur une interaction recherche-gestion (gestion adaptative), et la prise en compte explicite de la notion d'incertitude paraissent des éléments essentiels au maintien des services écosystémiques fournis par la forêt.

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Mots-clés: biodiversité, gestion forestière, production de bois, protection contre les aléas naturels, stockage de carbone

Keywords: biodiversity, carbon storage, forest management, protection against natural hazards, wood production

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